Before the Commissioners appointed by Canterbury Regional Council

IN THE MATTER OF	The Resource Management Act 1991
AND	
IN THE MATTER OF	Applications by the Central Plains Water Trust and Central Plains Water Ltd. to Take and Use Water for Irrigation in the Central Plains area.

Section 42A Officer's Report

Date of Hearing: 25 February 2008

Report of CARL ROBERT HANSON

INTRODUCTION

Background

1. The Central Plains Water Trust has applied to the Canterbury Regional Council for resource consents to take water from the Rakaia and Waimakariri rivers and use it to irrigate 60,000 hectares of land between the two rivers. The irrigation scheme is called the Central Plains Water Enhancement Scheme ("the CPW scheme").

2. The proposed irrigation has the potential to affect groundwater quality beneath and down-gradient of the scheme area because it will allow an intensification of farming in the scheme area. More intensive farming could result in increased amounts of nitrate, pathogenic micro-organisms, pesticides, and other contaminants being leached into the groundwater from the soil.

3. My report will provide information and advice related to the effects of the proposed irrigation on groundwater quality.

4. My report is supplementary to the Section 42A report prepared by the Canterbury Regional Council for the above consent application. Full details of the consent application are provided in that report.

Qualifications and experience.

5. My full name is Carl Robert Hanson. I have been employed by the Canterbury Regional Council as a Groundwater Quality Scientist since June 2001. Prior to that I was employed as a consulting groundwater scientist in Dunedin and in the USA. I hold a Bachelor of Science degree in geology from Syracuse University in New York, USA, and a Master of Science degree in geology from Dartmouth College in New Hampshire, USA.

6. I have worked as a groundwater scientist since 1990, specialising in the fate and transport of contaminants in soil and groundwater. My work with the Canterbury Regional Council includes the design and management of projects to investigate, monitor, and report on the chemical and microbiological quality of groundwater in the region.

7. In previous jobs, I was involved in a number of field trials and other investigations into the environmental fate and transport of pesticides and other agricultural chemicals in soils and groundwater. I was also involved with investigations of soil and groundwater contamination on numerous industrial sites in the United States and New Zealand, ranging from small scale industries to large-scale “Superfund” sites in the US.

Scope of my report

8. My report will provide information and advice related to the effects of the proposed irrigation on groundwater quality. It is primarily a review of the consent applicant's assessment of these effects. In writing my report, I have considered information in the following reports that have been submitted as part of the consent application:

- URS, 2006. Central Plains Water Enhancement Scheme: Assessment of Environmental Effects for Resource Consent Applications to Canterbury Regional Council. Report prepared for Central Plains Water Trust by URS New Zealand Ltd. (Christchurch). Report number 42156547.66140 \ AEE R001C, dated 23 June 2006.

- Aqualinc, 2006. Central Plains Water Enhancement Scheme – Assessment of Effects on the Groundwater Environment. Report prepared for URS New Zealand, Ltd. by Aqualinc Research Ltd. Report number L05248/2, dated June 2006.
- ESR, 2006. Report on environmental effects of Central Plains Water irrigation scheme, contaminant loading and reduction estimates. Report prepared for Aqualinc Research Ltd. by the Institute of Environmental Science and Research Ltd, dated May 2006.
- Crop & Food, 2005. Estimates of nitrogen and phosphorus leaching under various land uses in Canterbury. Report prepared for Aqualinc Research Ltd. by the New Zealand Institute for Crop & Food Research Ltd. Confidential Report number 1533, dated December 2005.
- Aqualinc, 2007. Canterbury Groundwater Model 2. Report prepared by Aqualinc Research Ltd. Report number L07079/1, dated September 2007.
- URS, 2007. Central Plains Water Ltd – Nitrate Contamination Assessment. Report prepared for Central Plains Water Ltd. by URS New Zealand Ltd. (Christchurch). Report number 42156547, dated 27 November 2007.
- Brief of evidence of Julian James Weir, prepared in January 2008 for this hearing.

9. I have also reviewed the reports of David Scott and Howard Williams for the Canterbury Regional Council, and I have discussed the technical aspects of my report with Dr. Vince Bidwell of Lincoln Ventures Ltd.

10. My report will consider:

Section C: the description of the groundwater system and existing groundwater quality beneath the Central Plains

Section D: the potential effects that the CPW scheme might have on micro-organisms, phosphorus and pesticides in the groundwater beneath the Central Plains

Section E: the potential effects that the CPW scheme might have on nitrate in the groundwater beneath the Central Plains

Section F: potential changes in groundwater quality within the Christchurch groundwater system

11. Such evidence is within the ambit of my expertise.

12. I acknowledge that I have read the code of conduct for expert witnesses contained in the Environment Court's Practice Note dated 31 March 2005. I have complied with it when preparing my report and I agree to comply with it when I give oral evidence.

Summary of my conclusions

13. The applicant has provided a fair assessment of the existing groundwater quality beneath the Central Plains.

14. The CPW scheme is unlikely to have significant adverse effects on phosphorus, pesticides, or pathogenic micro-organisms in the groundwater beneath the Central Plains.

15. Contrary to the applicant's conclusions, the CPW scheme will cause an increase in nitrate concentrations in groundwater beneath the Central Plains and in spring-fed streams in the lower part of the plains. The chance of this increase being kept within acceptable limits will be greatest if nutrients on farms are managed to minimise nitrate leaching.

16. The scheme may have a minor impact on groundwater quality in the southern part of the Christchurch groundwater system. Private and community water supplies elsewhere in the Central Plains area might be affected by increased nitrate concentrations.

NOTES

Central Plains area and CPW scheme area

17. In my report, I will refer to the "Central Plains" area as the area between the Waimakariri and Rakaia rivers, and between the foothills and the coast, excluding the Christchurch groundwater system.

18. I will refer to the "CPW scheme" area as only the area within the scheme boundary, as shown in Figure 1-1, Section 1.2, page 1-2, of the June 2006 Assessment of Environmental Effects (URS, 2006).

Units of measurement – nitrate

19. All nitrate concentrations detailed in my evidence will be expressed as nitrate nitrogen, rather than nitrate ion. The units of measure are milligrams of nitrogen per litre, or “mg/L”. Note that mg/L is equivalent to grams per cubic metre (g/m^3), the units used in the applicant’s assessment.

Drinking-water standard – nitrate

20. The Maximum Acceptable Value (MAV) set by the New Zealand Ministry of Health for nitrate in drinking water is 50 mg/L when expressed as nitrate ion. When expressed as nitrate nitrogen – the units used in my evidence – the MAV is equivalent to 11.3 mg/L. The MAV has been set to minimise the short-term health risk to bottle-fed infants younger than about 6 months old (Ministry of Health, 2005).

DESCRIPTION OF CENTRAL PLAINS GROUNDWATER SYSTEM

General

21. A description of the groundwater system beneath the Central Plains area, including the quality of the groundwater, is provided in Section 6.3 of URS (2006). This description is taken largely from Aqualinc (2006). A further description of existing nitrate concentrations in groundwater beneath the CPW scheme area is provided in Section 2.3.2 of URS (2007). I am generally in agreement with these descriptions, so I will limit my remarks to a few comments.

Aquifers, aquitards, and the depth of groundwater contamination

22. I am not convinced that there are distinct layers of aquifers and aquitards that can be defined across the entire Central Plains area, as suggested by URS (2006) and Aqualinc (2006). Certainly, I do not accept that there are extensive aquitards across the area that significantly impede the vertical flow of groundwater between aquifers. The Canterbury Plains are formed by a series of alluvial fans that have been built up by deposition from braided rivers flowing out of the Southern Alps. Such a depositional environment is not conducive to the formation of laterally extensive layers of any kind. Howard Williams gives a more detailed description of the Central Plains aquifer geology in his evidence.

23. In terms of groundwater quality, the significance of this is that there is no geological barrier that keeps nitrate (and other contaminants from the land surface) contained within a shallow "aquifer". I agree that these contaminants do generally remain in the shallower groundwater, but this is a function of groundwater recharge and flow patterns rather than geology. Therefore, the depth to which contaminants penetrate in the groundwater will change if recharge and flow patterns change.

24. I note that the later URS report (2007) relies less on the presence of distinct aquifers than the earlier (2006) report did. I note also that Julian Weir, in his evidence (based on the revised Canterbury Groundwater Model - Aqualinc, 2007), does allow for vertical flow between the aquifers and acknowledges that there are no impermeable boundaries between aquifers (paragraph 12, “Key Points”), though he maintains the general definition of laterally extensive aquifers and aquitards.

Existing nitrate concentrations

25. URS (2006) and Aqualinc (2006) provide a description of nitrate concentrations in groundwater beneath the Canterbury Plains. In general terms, it is a fair description, based on data held by the Canterbury Regional Council. Their description uses data from beyond the Central Plains area, but in fact, the general picture is similar whether considering data from the entire Canterbury Plains, the Central Plains, or only the CPW scheme area.

26. URS (2007) provides a plot of the statistical distribution of nitrate concentrations recorded in the Canterbury Regional Council's water quality database, using only data from the CPW scheme area. Again, this gives a fair, general picture of nitrate concentrations in the area.

27. However, it is very difficult to give a precise assessment of nitrate concentrations in groundwater beneath the Central Plains area, or beneath any part of the Canterbury Plains. Data held by the Canterbury Regional Council provide a general picture of the range and geographic distribution of nitrate concentrations, but the data are not a completely random or representative sample of the region's groundwater. A mean nitrate concentration derived from the data for any part of the groundwater system is probably only accurate to within 1-2 mg/L.

28. Therefore, any comparison of model results with Canterbury Regional Council data, such as that undertaken by URS (2007), must acknowledge that the data do not provide a complete picture of groundwater quality in the area.

MICRO-ORGANISMS, PHOSPHORUS AND PESTICIDES
Micro-organisms

29. URS (2006) states that pathogenic micro-organisms have a relatively short lifetime and do not travel far in groundwater. From this, it concludes that micro-organisms do not pose a significant threat to water quality. This conclusion is supported by ESR (2006), particularly given that the irrigation from the CPW scheme will be applied by spray and not by flood.

30. I agree with this conclusion. Where the water table is within a few metres of the ground surface, dairy paddocks may increase the risk of faecal contamination in groundwater, particularly where the paddocks are flood-irrigated (Close *et al.*, 2005). However, it is my understanding that flood irrigation will not be used in the CPW scheme area. Additionally, the water table is many metres below the ground surface beneath most of the scheme area, so the risk that micro-organisms will reach the groundwater is low.

Phosphorus

31. The URS assessment (2006) concludes that the risk of significant phosphorus contamination in groundwater as a result of the CPW scheme area is low. Their conclusion is supported by Crop & Food (2005). I agree with this conclusion.

32. Dissolved reactive phosphorus (DRP) was included as a determinand in the Canterbury Regional Council’s annual groundwater quality survey in September-December 2007. Groundwater samples were collected from approximately 300 wells across Canterbury. With few exceptions, DRP concentrations in samples from the Canterbury Plains were less than 0.01 mg/L. Higher concentrations (generally between 0.01 and 1.0 mg/L) were found in the coastal area of the Canterbury Plains from Lake Ellesmere to Waipara, in the downland area south of Timaru, and in the Cheviot-Spotswood and Kaikoura areas.

33. These results suggest that DRP concentrations are affected more by aquifer geology than by land use, and that the risk of significant phosphorus leaching in the CPW scheme area is low.

Pesticides

34. The URS assessment (2006) concludes that the risk of significant pesticide contamination in groundwater as a result of the CPW scheme area is low. Their conclusion is supported by ESR (2006). I agree with this conclusion.

35. Pesticides have not been found widely in Canterbury groundwater. The most frequent detections have been in the Levels Plain area in the southern Canterbury Plains, where groundwater is shallow and the land is widely used for cropping. Even in this area, most concentrations detected have been well below any drinking-water standards.

36. The greatest risk of significant pesticide contamination would arise if intensive cropping, rather than dairy, became the predominant land use in the CPW scheme area. Even then, the risk would be limited to areas where groundwater is shallow, primarily near the Selwyn River tributaries. Over most of the CPW scheme area, the water table is probably too deep for pesticide contamination to be a significant risk.

NITRATE

Summary of my conclusions

37. Contrary to the conclusions in the applicant's assessment (URS, 2007), land use intensification associated with the CPW scheme will cause an increase in nitrate concentrations in the groundwater beneath the Central Plains.

38. Concentrations beneath the scheme area will increase because elevated nitrate concentrations will extend to greater depths beneath the water table.

39. Concentrations in shallow groundwater down-gradient of the scheme area will increase because the deeper groundwater derived from the scheme area will have less capacity to dilute them.

40. Higher nitrate concentrations in the shallow groundwater will cause higher concentrations in the spring-fed streams in the lower part of the Central Plains.

41. The changes in groundwater quality won't be uniform across the scheme area. The greatest changes are likely to occur in the Te Pirita area, where forestry and dryland grazing will give way to irrigated dairy. In the Darfield area, where dry crop land will be irrigated, there may be little change in groundwater quality, depending on how crops are managed.

42. It is not possible to predict the magnitude of nitrate concentration increases with any certainty. It is likely that in some cases, the increases will exceed objectives in the Canterbury Regional Council's Proposed Natural Resources Regional Plan, and some of the increases could have implications for public health.

43. At the same time, it is possible that the overall increase might be within acceptable limits. The chances for this outcome will be greatest if nutrients on farms are managed to minimise nitrate leaching.

44. I therefore recommend that if the consent is granted, conditions should be placed on the consent to ensure proper nutrient management.

Irrigation and nitrate leaching – general

45. Before I discuss the applicant's assessment specifically, I will briefly review the general reasons why the development of CPW scheme might cause an increase in nitrate leaching.

46. The proposed irrigation will allow an intensification of farming within the CPW scheme area. This in turn will cause an increase in the amount, or mass, of nitrate that is leached to groundwater.

47. Intensification of farming means an increase in plant production – an increase in crops and pasture production. To achieve greater plant production, greater amounts of mineral nitrogen, primarily in the form of nitrate, need to be maintained in the soil. More nitrate in the soil, combined with more water being applied to the soil through irrigation, results in more nitrate being leached from the soil into the groundwater.

48. Greater pasture production also allows higher stocking rates, which result in greater returns of urine and faecal material to the soil. In grazed pasture systems, urine patches are the greatest source of nitrate leaching, because the amount of nitrogen applied in a urine patch is far more than plants can use. Higher stocking rates lead to more urine patches and more nitrate leaching. This effect is not restricted to irrigated land. Dairy cows commonly spend winter months, when leaching potential is greatest, on non-irrigated land.

49. Faecal material increases nitrate leaching over longer time periods by building up the fertility of the soil. In many ways, increased soil fertility is a desirable outcome, but it does mean an increase in the amount of leachable mineral nitrogen in the soil profile, and therefore an increase in nitrate leaching.

50. In summary, all of these processes **-** increased fertiliser use, more urine patches, increased deposition of faecal material, and increased soil fertility – will increase the amount of nitrate in the soil profile, and they will therefore increase the mass of nitrate that is leached from the soil into the groundwater.

Applicant's assessment

51. The applicant's assessment of the effects that the CPW scheme will have on nitrate leaching and nitrate concentrations in groundwater is presented in a report by URS, dated 27 November 2007. This report supersedes an earlier assessment by Aqualinc (2006), which was summarised in an earlier URS report (2006). My comments will disregard the earlier assessment and will focus instead on the November 2007 report.

52. URS (2007) uses a mixing model to predict the changes in nitrate concentrations that will occur as a result of the development of the CPW scheme.

53. Inputs to the model include the mass of nitrate leached from the land surface, the volume of water that drains through the soil, and the volume of water that seeps into the ground from water races, canals, and the Selwyn River system.

54. For a given combination of land use, soil type and rainfall, a mass of nitrate nitrogen is assumed to be leached from the soil into the groundwater. This mass of nitrogen is mixed with an associated volume of soil drainage water and a volume of water from races, canals and rivers. The result is a nitrate nitrogen concentration.

55. The model was run thousands of times, each time using a different set of input values, to develop a predicted frequency distribution of nitrate concentrations in the groundwater beneath the scheme area. The report compares this frequency distribution with data from the Canterbury Regional Council.

56. Based on this comparison, the report concludes that there will be no significant change in the distribution of nitrate concentrations in the groundwater beneath the scheme area, and therefore there will be no adverse effects on nitrate concentrations in groundwater or in groundwater-fed surface water (spring-fed streams and Lake Ellesmere).

General comment on URS conclusion

57. The URS report concludes that there will be increases in both the mass of nitrate and the volume of water that enter the groundwater beneath the CPW scheme area. According to the report, however, these two increases will balance each other, so that concentrations in the groundwater beneath the scheme area will not change.

58. This result needs to be considered with caution. It refers not to absolute nitrate concentrations, but to the statistical distribution of nitrate concentrations (shown in graphs such as Figure 3-1, page 3-3 of URS, 2007) that will be found within a shallow groundwater zone that varies in depth and volume.

59. Note that the term "shallow groundwater zone" is my own. It is not used in the URS report, but the concept is implicit in that report. I will discuss the concept further in the next section.

60. I will then demonstrate that because the shallow groundwater zone will contain more nitrate and more water, elevated nitrate concentrations will extend to deeper levels within the groundwater. In my opinion, this means – contrary to the URS conclusion – that the CPW scheme will cause an increase in nitrate concentrations in groundwater.

61. I will also point out that there is considerable uncertainty in many of the inputs to the model, and that the range of potential effects that the CPW scheme might have on nitrate concentrations in groundwater is much greater than what is suggested in the URS report.

Conceptual model – shallow groundwater zone

62. The URS model calculates nitrate concentrations in a mixture of water from three sources, listed in Section 2.2.3, page 2-4:
- (a) land drainage (or soil drainage, containing nitrate leached from the soil)
- (b) upper catchment stream losses (seepage from the Selwyn River system, containing no nitrate)
- (c) losses from canals and stockwater race systems (also containing no nitrate)

63. The water from these three sources is mixed together to form a body of groundwater that I will refer to as the "shallow groundwater zone" (again, this is my term, and it is not used in the URS report). Nitrate concentrations are calculated by mixing the annual volume of water from these three recharge sources with an annual mass of nitrate leached from the land surface.

64. The zone of shallow, nitrate-contaminated groundwater extends from the water table down to an unspecified depth, sitting on top of a zone of deeper groundwater that is recharged by seepage from the Rakaia and Waimakariri rivers. Since the water in the rivers has very low nitrate concentrations, the deep groundwater also has very low concentrations.

65. In the URS model, the shallow and deep groundwater zones are completely separate. There is no mixing between them. The model calculations exclude the deep groundwater and calculate nitrate concentrations only in the shallow groundwater zone.

66. The conceptual model is necessarily a simplification of the Central Plains groundwater system, but in general, I agree with it. My main comments on the conceptual model are:

- In reality, there will be substantial mixing between the shallow and deep groundwater zones. The boundary between these zones will be a diffuse, poorly defined transition zone.
- I question the degree to which the recharge from the Selwyn River system is mixed with the shallow groundwater zone.
- Groundwater quality is not uniform across the shallow groundwater zone. It reflects variations in historical land use as well as variations in groundwater recharge and flow patterns.

67. These factors highlight some of the uncertainty associated with the model results. Any result derived from the model will have some potential error associated with it, and in my opinion, the URS report understates the scale of this potential error. I will discuss this later in my report.

Mixing depth – thickness of the shallow groundwater zone

68. In the previous section, I described the concept of a shallow groundwater zone. In this section, I will demonstrate that the thickness of this zone will increase as a result of the CPW scheme, and hence the scheme will increase the amount of nitrate contamination in the groundwater.

69. The thickness of the shallow groundwater zone corresponds to what URS (2007, Section 2.2.3) refers to as the "mixing depth". It is the vertical distance between the water table and the top of the deep zone of clean groundwater (assuming no interaction between the shallow and deep groundwater zones, as in the conceptual model I described in the previous section).

70. The absolute mixing depth is very difficult to determine. It is a function of the rates of inflow from clean and contaminated recharge sources, a function of aquifer properties including porosity, hydraulic conductivity and aquifer thickness, and a function of groundwater flow and dispersion processes within the aquifer. In addition, the boundary between the shallow and deep groundwater zones is not a distinct surface, but a diffuse zone of mixing.

71. Because of these complexities, the URS model does not attempt to calculate the mixing depth. The model is based solely on the volume of recharge to the shallow groundwater zone, so it only calculates the distribution of nitrate concentrations within this zone, without defining the full extent of the zone.

72. This strategy is very useful for focussing on the changes in nitrate contamination without having to describe complex aquifer processes which, in reality, are poorly understood. However, it must be kept in mind that if groundwater recharge patterns change, then the mixing depth will also change. Specifically, if the volume of recharge to the shallow groundwater zone increases relative to the total groundwater flow, then the mixing depth must increase.

73. If the mixing depth increases, then elevated nitrate concentrations will occur at greater depths beneath the water table, and wells will need to be drilled to greater depths if they are to intercept "clean" water with low nitrate concentrations. In my opinion, this would represent an increase in nitrate concentrations in the groundwater.

74. In the following paragraphs, I will develop a rough estimate of how much the mixing depth might increase. I will use input values taken directly from the URS report. Therefore, the results of the calculations I discuss here are implicit in the URS report, though that report does not present the results in detail. My calculations have been developed in consultation with Dr. Vince Bidwell, Senior Research Engineer at Lincoln Ventures Ltd., who specialises in the interactions between land use and groundwater.

75. In the URS report, the annual recharge to the shallow groundwater zone includes soil drainage, race and canal leakage, and seepage from the Selwyn River system.

- From the drainage rate distributions in Appendix A of the URS report, and the land use areas listed in Tables 2-3 and 2-4, I estimate annual soil drainage inputs of 380 million cubic metres per year (MCM/yr) for the pre-scheme scenario, and 500 MCM/yr for the post-scheme scenario.
- From Tables 2-1 and 2-2 of the URS report, I calculate inputs to the shallow groundwater zone from clean water sources to be 193 MCM/yr pre-scheme and 275 MCM/yr post-scheme (using "typical year" values).
- Total recharge to the shallow groundwater zone, then, is 573 MCM/yr pre-scheme and 775 MCM/yr post-scheme. This represents a 35% increase as a result of the scheme.
- As a check on these numbers, I also estimated nitrate mass loadings to the shallow groundwater zone. Using the nitrate leaching rate distributions from Appendix A and the land use areas listed in Tables 2-3 and 2-4, I calculated an increase of about 50%, from 2,600 tonnes pre-scheme (across the entire 105,000 hectare scheme area) to 3,900 tonnes post-scheme. Based on the overall conclusion in the URS report, the increase in nitrate mass loading should match the increase in recharge, which is 35%, whereas I calculated an increase of 50%. This variation illustrates the potential error in my estimates; I cannot duplicate the URS calculations precisely (because I don't have full access to the detailed inputs or modelling software they used), so my calculations are only approximate.

76. From Tables 2-1 and 2-2 of the URS report, I calculate inputs to deep groundwater from the Rakaia and Waimakariri rivers to be 469 MCM/yr pre-scheme and 471 MCM/yr post-scheme.

77. This brings total groundwater recharge at the down-gradient boundary of the CPW scheme area to 1,042 MCM/yr pre-scheme and 1,246 MCM/yr post-scheme.

78. Assuming that the thicknesses of the shallow and deep groundwater zones are proportional to the relative recharge rates, and assuming an aquifer thickness of 250 metres (roughly consistent with the layer thicknesses in Aqualinc, 2007, Table 4-1, page 44), the thickness of the shallow groundwater zone (the mixing depth) is calculated as 137 metres pre-scheme and 162 metres post-scheme. Therefore, the mixing depth increases by roughly 24 metres as a result of the scheme.

79. Based on Mr. Weir's evidence, the water table beneath the scheme area is predicted to rise by roughly 10 metres. This would mean that the interface between the shallow and deep groundwater zones would move downward by roughly 14 metres.

80. Keep in mind that these calculations are very rough, and really only useful as order-of-magnitude estimates. However, they indicate that the mixing depth will increase by something on the order of 15% to 20%, representing an actual depth increase up to a few tens of metres, rather than, say, only a fraction of a metre.

81. The URS report does acknowledge that the mixing depth will increase, but only "slightly" (Section 3.6, page 3-8). In my opinion, a 15% to 20% increase is significant, rather than just a slight increase.

82. In summary, it may be that within the shallow groundwater zone, the statistical distribution of nitrate concentrations does not change. The maximum, mean, and median values may all remain constant if the increase in mass loading is balanced by an increase in drainage. But it is incorrect to say that this is not a change in nitrate concentrations in the groundwater. The thickness of the contaminated shallow groundwater zone will increase. There will be more nitrate in the groundwater, and elevated nitrate concentrations will extend to greater depths. This represents an increase in nitrate concentrations in the groundwater.

Increased nitrate concentrations down-gradient of the CPW scheme area

83. An increase in the mixing depth and the mass of nitrate in the groundwater beneath the CPW scheme area will mean that this groundwater has less capacity to dilute nitrate in soil drainage water from land down-gradient of the scheme area. Therefore, nitrate concentrations in shallow groundwater down-gradient of the scheme will increase.

84. As it flows toward the coast, groundwater derived from the CPW scheme area will mix with soil drainage from land down-gradient of the scheme area. In other words, shallow groundwater down-gradient of the scheme area will be diluted by mixing with groundwater derived from the scheme area itself.

85. If there is more nitrate in the groundwater from the scheme area, then there will be less capacity to dilute nitrate concentrations down-gradient of the scheme. Therefore, nitrate concentrations in shallow groundwater down-gradient of the scheme will increase as a result of scheme development.

86. Annual average concentrations will increase compared with current levels, but short-term peak concentrations may increase by an even greater amount. Nitrate concentrations at any given point in the groundwater are not constant throughout the year. They tend to be higher in late winter and spring, and lower in autumn. In the winter of 2006, after a heavy snowfall in June of that year, concentrations rose dramatically (by 5 to10 milligrams per litre in some cases) in shallow wells throughout the Canterbury Plains. In most of these cases, the concentrations decreased again over the following year.

87. In my opinion, this sort of seasonal variation will become more pronounced in the area down-gradient of the CPW scheme if long-term average concentrations rise.

88. Finally, if nitrate concentrations in the shallow groundwater increase, then nitrate concentrations in the spring-fed, lowland streams will also increase because these comprise various proportions of discharge from shallow and deep groundwater.

Nitrate leaching rate distributions used in the URS model

89. In the URS model, the mass of nitrate leached to groundwater is a function of the land areas in Tables 2-3 and 2-4 (URS 2007, Section 2.3.3, pages 2-6 and 2-7) and the corresponding nitrate leaching distributions in Appendix A.

90. URS uses multiple runs of the model to simulate the variation in nitrate concentrations that will occur across the CPW scheme area. For each of the sub-regions listed in Table 2-3 (URS, 2007), the model is run 5000 times, each run selecting a different loading rate at random from the corresponding nitrate leaching distribution in Appendix A.

91. Therefore, the distributions in Appendix A are critical to the outcome of the model and the report conclusions. In my opinion, these distributions have some important shortcomings.

92. First, the report provides very limited information as to how these distributions were developed.

- The distributions for cropping losses were apparently developed from modelling work done by Crop & Food Research, Ltd., but no details are given, and the connection between the distributions and the Crop & Food report (2005) is not at all clear.
- The model appears to have used the same distributions for dry and irrigated crops, even though these are divided into separate land areas in Table 2-3, but again, this is not clear.

- No justification at all is given for the dryland pasture distribution
- The source of the distribution for irrigated pasture (including dairy) is described in more detail. The distribution is based on a review and interpretation of the results of several published studies, listed in Table 2-5 (URS 2007, page 2-9). This is a reasonable way to develop a distribution, but I question whether the literature review was complete and whether the interpreted distribution was reasonable. I will discuss this in the next section.

93. Second, in my opinion, all of the distributions are too narrow. In other words, I think that leaching rates from any given land use are far more variable than what the distributions in Appendix A imply.

94. Third, the model assumes that drainage volume and nitrate loading are completely independent. This is probably not correct. The relationship between these two variables is poorly understood, but there is likely to be some relationship between them.

Nitrate leaching losses for irrigated pasture

95. In my opinion, the distribution for leaching from irrigated pasture is too narrow.

96. The distribution is included in Appendix A, and it is presented in more detail in Figure 2-4 (URS 2007, page 2-10). Based on this distribution, the leaching loss would be greater than 86.7 kilograms of nitrogen per hectare per year (kgN/ha/yr) in only 5% of all cases. In most cases, losses would be in the range of about 40 to 80 kgN/ha/yr. As I have noted, this distribution was based on a literature review summarised in Table 2-5.

97. I am not familiar with most of the papers listed in Table 2-5, but it is likely that in many of these studies, soil drainage rates were considerably lower than those shown in Appendix A of the URS report.

98. For irrigated pasture, the drainage rates used in the URS model were generally in the range of 500 to 700 millimetres (mm) per year, based on a review of the drainage distributions in Appendix A. In contrast, the drainage rates for the Monaghan *et al.* (2000, 2002) study listed in Table 2-5 were about 360 to 370 mm. That study found nitrate leaching losses of 25 to 56 kgN/ha/yr, depending on stocking rate and fertiliser application.

99. On the other hand, the Ledgard *et al.* (1999) study listed in Table 2-5 found annual leaching losses ranging from 20 to 204 kgN/ha/yr, with drainage rates of 535 mm to 668 mm. These drainage rates are within the range of values used in the URS model.

100. Two other important studies, reported by Di and Cameron (2002) and Silva *et al.* (1999) are not listed in Table 2-5. These were lysimeter studies carried out at Lincoln University. They were not field-scale studies like most of those listed in Table 2-5, but instead were carried out using lysimeters 500 mm in diameter.

101. The main difference between the two studies was that Silva *et al.* (1999) used a deep Templeton soil, common in the Lincoln area, whereas Di and Cameron (2002) used a shallow Lismore soil, similar to the soils in the Te Pirita area. In fact, compared to all the studies listed by URS in table 2-5, the Di and Cameron (2002) study was the only one to use soils that are common in the CPW scheme area.

102. The annual drainage rates from the Templeton soils (Silva *et al.*, 1999) was reported at 410 mm, and leaching losses ranged from 33 to 60 kgN/ha/yr, depending on soil treatments. The drainage rates and leaching losses from this study were comparable to those in the Monaghan *et al.* (2020, 2002) study.

103. Annual drainage rates from the Di and Cameron (2002) study, using Lismore soils, were about 610 mm and 880 mm, for the two years of the study, and leaching losses ranged from 112 to 162 kgN/ha/yr. The soils and soil drainage rates in this study were comparable to those assumed for irrigated pasture in the URS model. The drainage rates were also comparable to those reported by Ledgard *et al.* (1999), and the leaching losses were comparable to the upper end of the range reported in that study.

104. These results suggest to me that nitrate losses from the CPW scheme area could exceed 100 kgN/ha/yr much more frequently than the distribution in the URS report implies. This would make the nitrate leaching distribution (URS 2007, Figure 2-4) much broader, and it would make the predicted distribution of nitrate concentrations in groundwater (URS 2007, Figure 3-1, page 3-3) broader as well, with a higher portion of the concentrations exceeding the MAV of 11.3 mg/L.

Soil drainage versus nitrate leaching

105. URS report defended its nitrate leaching rate estimates by citing a graph from Monaghan (2002), shown in Figure 2-5, page 2-11 of the URS (2007) report.

106. This graph was misinterpreted. It does not show that nitrate concentrations in soil drainage are lower when annual drainage rates are higher. Instead, it merely shows that concentrations in soil drainage water from the same site decrease over the course of a year. The "cumulative drainage" on the horizontal axis is a surrogate for time elapsed from the start of the study, rather than a measure of total annual drainage.

107. In other words, early in the year, when less than 100 mm of water had drained from the plot, nitrate concentrations in the soil drainage ranged from about 2 to 13 mg/L. Toward the end of the year, after over 300 mm of water had drained, concentrations in the remaining drainage water did not exceed 4 mg/L.

108. Based on my knowledge of published literature, and on discussions with colleagues, I don't believe that the relationship between soil drainage rates and nitrate leaching is understood very well at all. Therefore, I think any assessment of potential nitrate leaching needs to acknowledge a strong possibility that higher soil drainage rates, such as those predicted for irrigated pasture in the CPW area, could be accompanied by higher nitrate leaching losses.

Winter grazing

109. If much of the CPW scheme area is converted to irrigated dairy pasture, then much of the non-irrigated land in the area is likely to be needed for winter feeding of the dairy cows.

110. Cows are commonly removed from the irrigated milking platform over the winter to prevent excessive pugging of the soil and improve pasture production for the next milking season.

111. The cows spend the winter on non-irrigated paddocks. These winter paddocks are commonly stocked quite heavily, and the cows are fed either by strip-grazing a fodder crop, or by importing feed from outside the farm.

112. The effects of these practices have not been studied in detail, but they have the potential to cause very high leaching rates on non-irrigated paddocks over the winter. Therefore, the development of the CPW scheme could cause an overall increase in leaching rates on non-irrigated land within the scheme area as well as on irrigated land. The URS model does not appear to have accounted for this possibility.

Distribution of nitrate concentrations

113. I would like to comment a bit further on the results of the URS model, the distributions of nitrate concentrations in groundwater such as those in Figure 3-1. I have already discussed how these are statistical distributions and do not reflect absolute concentrations. In this section, I also want to point out that the distributions developed from the URS model do not show the same information as the distribution of nitrate concentrations in the Canterbury Regional Council 's groundwater sampling data.

114. The URS report uses a comparison of these two distributions to defend the reliability of its model. However, the two distributions are not comparable, and therefore the URS argument is not valid.

115. The Canterbury Regional Council’s data represent a set of instantaneous observations of groundwater quality. These observations were made at various locations in the groundwater system, in different years and at different times of the year. In contrast, the results of the URS model represent annual average concentrations.

116. I would expect the distribution of concentrations in the Canterbury Regional Council's dataset to be significantly broader than the annual average concentrations from the URS model. The Canterbury Regional Council's dataset contains samples with seasonal high and low concentrations, variations that are smoothed over in the annual average results.

117. In addition, the Canterbury Regional Council's dataset is not a completely random sample of the area, nor is there a particularly large number of data points for an area the size of the CPW scheme. This adds uncertainty to the interpretation of the distribution.

118. In summary, I would not expect the distribution of results from the URS model to be the same as the distribution of the Canterbury Regional Council's results. Therefore, in my opinion, the fact that the two distributions match does not provide strong evidence of the validity of the URS model.

Model uncertainty

119. The URS model provides one result, a single distribution of nitrate concentrations with very little discussion of the potential error associated with it.

120. The report does present some analysis to investigate the sensitivity of the model results to variations in some input parameters. Specifically, in Section 3.5 (pages 3-4 to 3-8), it presents results derived from decreasing soil drainage rates and/or nitrate leaching rates, and from decreasing the amount of clean water dilution, which might occur if the distribution network were piped.

121. However, in my opinion, this analysis only touches the surface of the uncertainty inherent in the model. Other inputs with uncertain values include the following.

122. **Nitrate leaching rates**: As I have discussed in previous sections of my report, I think there is a great deal more uncertainty in the leaching rates from different land uses than what is implied in the distributions shown in Appendix A of the URS report. Moreover, I am not convinced that the values used by URS are particularly conservative. In other words, I think the distributions under-estimate the potential for higher leaching losses, particularly from irrigated pasture and from dry pasture used for winter feeding. In previous sections of my report, I have illustrated that nitrate concentrations in groundwater will increase even using the distributions in the URS report. If actual leaching rates are higher, then nitrate concentrations in groundwater will increase by even greater amounts.

123. **Area of land to be irrigated**: The assessment is based on the assumption that the scheme will only result in 36,000 hectares of new irrigation, rather than the full 60,000 hectares that the scheme will ultimately irrigate. The assumption is that the 24,000 hectares of land within the scheme that is current irrigated will all become part of the scheme. However, I don't see any guarantee that this will occur, or that the groundwater consents associated with the land currently irrigated won't be transferred to other land that is not irrigated by the scheme. If the scheme results in more than 36,000 hectares of new irrigation, then the effects on groundwater quality will increase.

124. Aquifer properties: The URS assessment ignores the aquifer properties and groundwater flow and mixing processes beneath the Central Plains area. These properties are very poorly understood, but they have important implications for how the aquifer system copes with the increased loading of recharge water and nitrate, and how the CPW scheme will affect nitrate concentrations down-gradient of the scheme area, and in spring-fed streams and Lake Ellesmere.

125. Mixing between shallow and deep groundwater: Again, the degree of mixing between the shallow and deep groundwater zones has important implications for the depth to which nitrate contamination is found, and for the dilution of nitrate concentrations down-gradient of the CPW scheme area. I think the degree to which Selwyn River system contributes to shallow groundwater is also highly uncertain.

126. Spatial variation: The URS model treats the shallow groundwater zone beneath the entire scheme area as a single bucket, but in reality, nitrate concentrations in groundwater are not uniform across the area. Based on the Canterbury Regional Council's data, nitrate concentrations in the Te Pirita area are relatively low, rarely exceeding 5 mg/L (nitrate nitrogen). Concentrations in the Darfield area are higher, commonly in the range of 5 to 10 mg/L. In an area near Greendale, where the Waianiwaniwa and Hawkins rivers join the Selwyn River, concentrations above 10 mg/L have been fairly common.

127. Together, these uncertainties make it extremely difficult to predict the effects of the CPW scheme. In my opinion, the range of possible effects is much greater than what is suggested in the URS report.

Estimate of potential increases in nitrate concentrations

128. In the preceding sections, I have argued that nitrate concentrations in shallow groundwater down-gradient of the CPW scheme area will increase as a result of the scheme. I have also argued that nitrate mass loadings within the scheme area could be greater than that those predicted by the URS model.

129. However, I cannot quantify the increases in mass loading and nitrate concentrations in groundwater. There is too much uncertainty associated with almost all of the factors that influence nitrate concentrations in groundwater, including groundwater flow rates, recharge rates, soil drainage rates, and nitrate leaching rates from different land uses.

130. At any rate, the increases will not be uniform across the scheme area. The greatest increases are likely to occur in the Te Pirita area, where dry grazing farms and forestry land will be converted to intensive dairy pastures, and where nitrate concentrations have been relatively low. In the Darfield area, on the other hand, where there has historically been more cropping and nitrate concentrations are already higher, the increases from the CPW scheme may be relatively minor.

131. In my opinion, the scheme is likely to cause nitrate concentrations in at least some parts of the Central Plains to increase by more than 2 mg/L, the limit set by Objective WQL2 in the Canterbury Regional Council's Proposed Natural Resources Regional Plan.

132. In addition, exceedences of the MAV will be more frequent, particularly in the lower parts of the plains, where short-term exceedences of the MAV are already common after wet winters or large recharge events. Since many people in this area derive their drinking water from relatively shallow wells, these exceedences may have public health implications.

Possible mitigation

133. As I have stated, it is my opinion that the CPW scheme will cause nitrate concentrations in groundwater to increase, and in some cases, these increases will exceed acceptable limits. However, given the uncertainties that I have discussed in my report, it is also possible that overall, increases in nitrate concentrations will be within acceptable limits. The chances for this outcome will be greatest if nutrients on farms are managed to minimise nitrate leaching.

134. To this end, I strongly recommend that if the consent is granted, conditions should be placed on the consent to ensure proper nutrient management.

135. Nutrient management conditions have been recommended by Canterbury Regional Council staff, including myself, for a number of irrigation consents in the past. The wording of these conditions has varied from one consent to the next, and the usefulness of these conditions has not yet been tested. At the same time, it is my understanding that organisations associated with the CPW scheme are working to develop farm nutrient management plans. Rather than propose my own wording for a nutrient management condition, I prefer to wait to see what might come from this work.

Summary of conclusions regarding nitrate

136. The CPW scheme will cause an increase in the mass of nitrate in the groundwater system. As a result, there will be an increase in nitrate concentrations in groundwater beneath and down-gradient of the scheme. Nitrate concentrations in spring-fed streams in the lower part of the Central Plains will also increase, as will nitrate loading into Lake Ellesmere.

137. It is not possible to predict the magnitude of nitrate concentration increases with any certainty. It is likely that in some cases, the increases will exceed objectives in the Canterbury Regional Council's Proposed Natural Resources Regional Plan, and some of the increases could have implications for public health.

138. At the same time, it is possible that the overall increase might be within acceptable limits. The chances for this outcome will be greatest if nutrients on farms are managed to minimise nitrate leaching.

139. I therefore recommend that if the consent is granted, conditions should be placed on the consent to ensure proper nutrient management.

EFFECTS ON THE CHRISTCHURCH GROUNDWATER SYSTEM

140. URS (2006) concluded that water quality in the Christchurch groundwater system is unlikely to be affected by the CPW scheme. The brief of evidence prepared by Julian Weir (January 2008) for the CPW hearing supports this conclusion.

141. The basis for this conclusion is that only a small part of the CPW scheme area, in the eastern corner of the area, contributes groundwater to the Christchurch system. Most of the groundwater from the CPW scheme area flows further to the south, toward Lake Ellesmere.

142. The general groundwater flow directions discussed by URS (2006) and Mr. Weir are consistent with groundwater quality and piezometric data held by the Canterbury Regional Council. Those data suggest that for the most part, the groundwater that flows beneath Christchurch is derived from the Waimakariri River and from soil drainage from land between the city and the river.

143. There is some question, though, about the location of the divide between groundwater that flows to the north of Banks Peninsula, toward Christchurch, and groundwater that flows south of Banks Peninsula, toward Lake Ellesmere. Canterbury Regional Council data suggest that the divide crosses somewhere through the vicinity of Hornby, Wigram, and Halswell, but there is room for error in this interpretation.

144. Elevated concentrations (above 1 to 3 mg/L) and other major ions (such as chloride, sulphate, calcium, and sodium), as well as detections of hydrocarbons at low concentrations, have been recorded in groundwater beneath the southern part of Christchurch (in the area around Addington, Sydenham and neighbouring suburbs). The chemistry suggests that land surface drainage is a more significant source of groundwater there than in the northern part of the city.

145. The land surface contamination is found only in relatively shallow groundwater, generally less than 50 metres beneath the ground surface. This suggests that the sources of contamination are likely to be fairly local. But it is possible that groundwater in this area does receive some recharge from the wider Central Plains area.

146. The groundwater mounding caused by the CPW scheme has the potential to shift the divide between the Christchurch and Lake Ellesmere groundwater catchments further to the north. Mr. Weir's evidence suggests that this effect will only be minor, and that result seems reasonable to me. If the divide does shift, the wells in southern Christchurch are those most at risk of increased contamination.

147. The particle tracking paths in Appendices J and K of Mr. Weir's evidence, based on the Aqualinc groundwater flow model (Aqualinc, 2007), raise some questions in my mind as to the precise sources of groundwater beneath the city. In particular, Appendix K suggests that deep groundwater beneath Christchurch has come from the upper plains, following flow paths that cross beneath much of the CPW scheme area. On the other hand, Appendix J suggests that almost all of the soil drainage water from the land surface within the scheme area follows paths to Lake Ellesmere.

148. While it is possible that flow paths at different depths do criss-cross in this manner, the result seems overly complex to me. It appears to raise the possibility that changes in groundwater flow beneath the CPW scheme area could have significant effects on groundwater quality in Christchurch. David Scott will also discuss this issue in his report for the Canterbury Regional Council, but from my own perspective, I would like to see more work done on these flow paths before I accept the model result. In the meantime, I merely highlight this question as a point of uncertainty.

149. As a final note, I point out that while the CPW scheme probably does not pose a threat to most of Christchurch's water supply, there are many other water supplies in the Central Plains area that might be affected by increased nitrate concentrations. People who draw their water from relatively shallow wells are most at risk. Even in the current situation, nitrate concentrations in many of these wells exceed the MAV at times, particularly after wet winters. If the CPW scheme is developed, these exceedences are likely to become more common.

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